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TECHNICAL REPORT: NAVTRAEQUIPCEN IH-285

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THEORETICAL ANALYSIS OF THE PROPOSED PANORAMIC MOVING TARGET SCREEN SIMULATOR

Physical Sciences Laboratory
Naval Training Equipment Center
Orlando, Florida 32813

May 1977

Interim Report for Period October 1975 - January 1976

NAVAL TRAINING EQUIPMENT CENTER

ORLANDO, FLORIDA 32813

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Technical Report: NAVTRAEQUIPCEN IH-285

Theoretical Analysis of the Proposed Panoramic Moving Target Screen Simulator

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May 1977

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(The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.)

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An analysis is given of a proposed weapon fire simulator which effectively represents the Integrated Parapet Foxhole concept of defense. The training requirements and gaming configurations are outlined. The resolution of the projected display and perspective anomalies place constraints on the simulator configuration. Methods of simulating the weapon fire are proposed. Techniques for scoring are analyzed along with the probability of (Cont'd)

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simultaneous and identical hits. Requirements for sound are mentioned. Requirements for recording multiple target locations are derived. The Panoramic Motion Target Screen System appears feasible. There are no technological areas that will require an excessive amount of research.

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SECTION I

INTRODUCTION

This report presents the results of an analytical study of a proposed simulator known as the Panoramic Moving Target Screen (PMTS). The proposal called for the device to realistically simulate the military missions encountered in the Integrated Parapet Foxhole concept of defense. During the early phase of this technical evaluation, it was determined that there were a number of different combat missions which the Integrated Parapet Foxhole concept of defense addressed; and, that it would not be feasible to simulate all of these missions in one device. At that point, a technical memorandum was issued, detailing the problems involved in balancing the training requirements against the optical and physical constraints in a simulator.

Moreover, this triggered a coordination meeting at Fort Benning, Georgia, on 11 December 1975, to clarify which combat missions were to be simulated. The meeting considered the extent to which the training goals could be achieved in the different simulator approaches investigated. Several guidelines were produced. The user indicated that a 6:1 ratio of aggressor to friendly personnel was anticipated in the attack to be simulated. The attack was to cover a 4 or 5 squad front with the trainee squad covering the fronts of squads to its left and right. The front of the trainee squad would be covered by preprogrammed fire from adjacent squads. The aggressors would begin their approach at 400 meters, advance (being attrited) to 50 meters and then retreat. The whole mission would last approximately 10 minutes.

With these guidelines it was evident that previously planned approaches were not entirely satisfactory and would have to be modified, since they stressed self-protection of the squad, which occurs only at close ranges, and had somewhat different orientations of the fields-of-fire. This report will discuss parameters and tradeoffs required in the PMTS to simulate the combat mission outlined above.

SECTION II

SIMULATOR CONFIGURATION

The requirement is for a realistic battlefield display on which 10 men of a squad may direct fire from realistic foxholes and the fire may be observed by the 36 other men of the platoon. The front, which would normally be defended by a squad in the real idealized world, is illustrated in figure 1.

It can be seen that the five men who fire to the right (and the five men firing left) principally cover the front of the two adjacent squads. They partially cover the front of their own squad at very close ranges and the front of a fourth squad at extremely long ranges. The typical fields-of-fire for each man is 15° wide lying between 45° and 60° from a line perpendicular to the line of foxholes which are spaced 20 meters apart.

It has been previously suggested that a configuration using a single cylindrical screen having a 60 foot radius would suffice. The main defect in this approach is that the fields-of-fire of the foxholes do not overlap and hence provide a highly unrealistic simulation of the real world. It has become apparent that the training requirements must be the basis for the simulator configuration. What follows then is an approach toward the analysis of the configuration where a realistic simulation is integrated with the many limitations and constraints of the technologies involved. The number of interacting and conflicting constraints is large and complex. In this report two configurations are given which, in the time alotted, appear to be within the range of available compromises. First, consider the constraining technological elements: training mission, projected image resolution, perspective anomalies, projectors and screen brightness, and multiscreen display.

TRAINING MISSION

The principle purpose of the simulator is to instill confidence in the integrated parapet foxhole defensive system. The simulator will be operated by one platoon at a time. The ten riflemen of one squad will fire from the simulated foxholes onto the display screen while the three remaining squads will observe from a bleacher section.

The trainee squad will be part of an imaginary platoon and company defending the front. The fire from the imaginary units will appear on the screen along with the fire from the trainee squad; but the trainees and observers should be able to clearly differentiate between the two kinds of fire.

The trainee squad and its individual members will be scored for hits and misses; but this is not the primary purpose of the simulator. The trainee squad firing will only see a relatively small part of the screen; and the total effect of the integrated

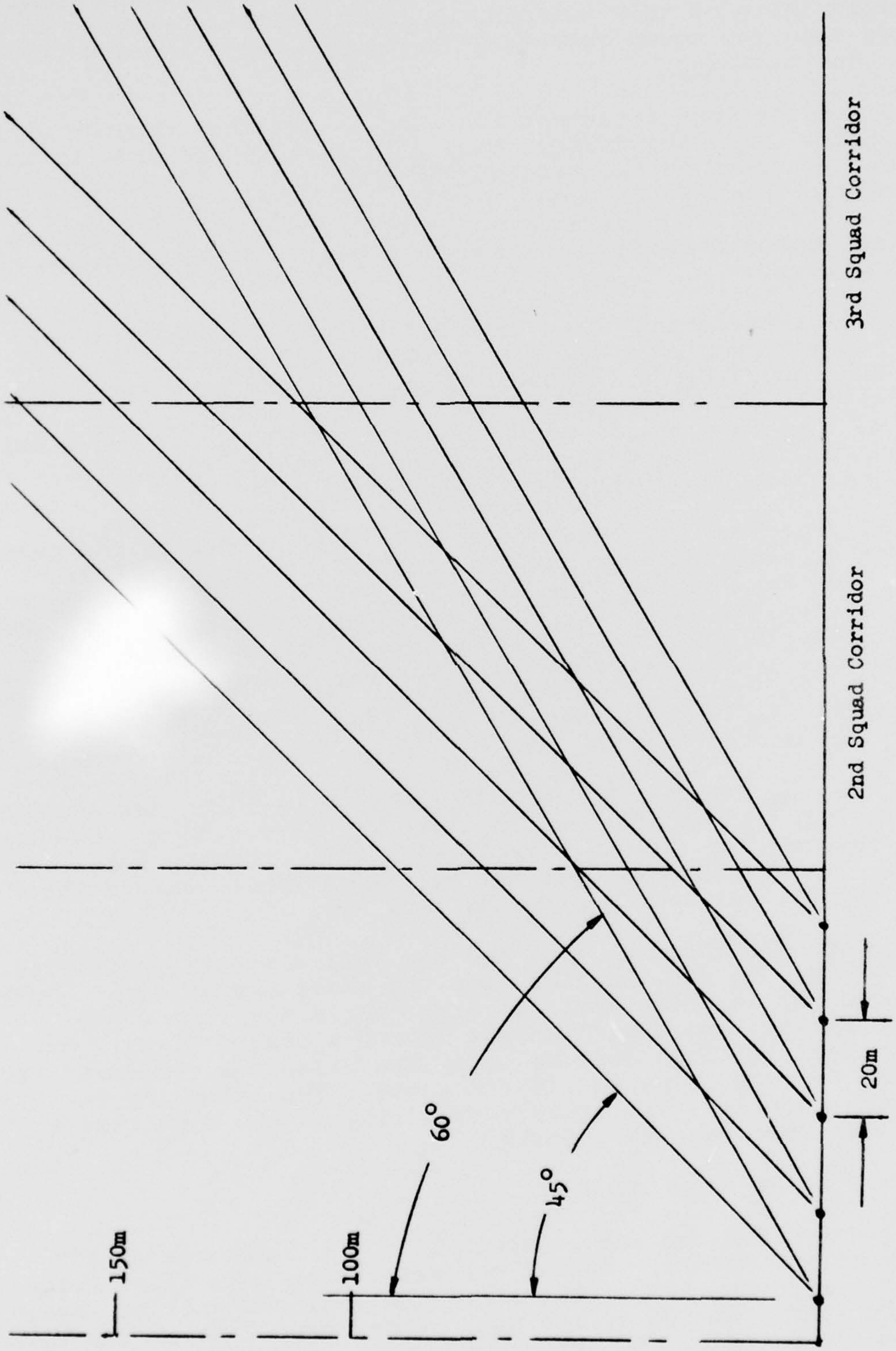

Figure 1. Idealized Real World

fire will not be observed by them. It is a notable and important characteristic of this training device that the observing squads, rather than the squad operating the device, will receive the more important training.

Since the more important training is obtained through watching others using the device, some effort should be made to insure maximum interest on the part of the observers. A display showing the continuous accumulative score of the operating squad and a final score left in place through the platoon exercise should add to competition between the squads and maximize the interest of the observers.

It is assumed that an attack will be on the front of more than one platoon, and, therefore, will be much wider than the active gaming area of the trainee squad in the foxholes. The attack will cover the entire width of the display. Also, it is assumed that the attack will consist of widely disbursed waves of individuals who appear only in the short intervals that they would normally appear between rushes from cover to cover.

The attackers will advance to within 50 meters of the platoon front and then begin a withdrawal with appropriate attrition. However, at the time the attackers reach the 50 meter line, other attackers will still be advancing into the 350 meter range area and the gaming area will cover the entire depth of the front within the range of the rifles. At its maximum, the attack will consist of approximately 60 enemy attackers per 100 meters of visible front, but no more than 15 or 20 will be visible at any one instant of time.

The trainee squad in the foxholes will begin to see attackers appear at 350 to 400 meters range who are advancing at some angle with respect to the fields-of-fire of the trainees. During the exercise, the defenders will see attackers appear within their fields-of-fire at ever shortening ranges.

The observing squads will see the entire attack developing. It is planned to add the fire from the imaginary adjacent squads, for instance, as white spots of light while the fire of the defending trainee squad will appear as red spots of light. Thus, the observers will be able to infer the defenders fields-of-fire from the pattern of white and red spots. The following technological constraints limit the versatility of the simulator to accomplish some desirable goals.

PROJECTED IMAGE RESOLUTION

A 1.8 x 0.5 meter man subtends 15.5 x 4.3 minutes of arc at a range of 400 meters. Normal eye resolution in complex imagery is 3 to 4 minutes of arc; but since the trainees will be looking intently at the images of the men, we can expect their resolution to be above average. Therefore, the best estimate of resolution

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requirements at the screen is on a scale of 2 to 6 minutes of arc, where 2 minutes is excellent, 6 minutes is poor, and 4 minutes is marginal resolution.

If the smallest fields-of-fire to be used is 15°, and we adopt 3 minutes of arc as the system performance criteria, then there must be 300 line pair resolution elements in each 15° of screen in order to achieve the desired resolution. If 2 minutes of arc are used as the resolution criteria, the projected display must be capable of 450 line pair resolution elements per 15° of screen.

A resolution element is the distance on the film, or projected image, required to portray a change in density or intensity, respectively. The image of a man at close to minimum resolution would be two resolution elements wide; and, when viewed from a very short distance, would appear unsharp. Where eye resolution (approximately 1 minute of arc) is very close to the image resolution, the eye does not see the unsharp edges and, because of experience, tends to assume sharpness. Where the angular eye resolution is greater than the projected angular image resolution, the eye can see the unsharpness of the image edges.

Where the contrast of an edge is high, the eye tends to interpret edges as sharp more often than when the edges are low contrast. The majority of our scene edges will be low contrast. In this trainer the trainees will often be looking at very small images with low contrast; so the desired resolution must be somewhat higher than normal movie productions.

It will be shown that the configuration of the simulator, its angular display, the number and size of projectors, and the size of the building used, are dependent to a large degree on the definition of "adequate resolution" used. For these reasons, we strongly recommend that the usual educated guess give way to a statistical measurement.

The test for resolution should require that the camera type, lens, film, projector, projector magnification, and screen to be used in the final device, be used in the test. The target should have a configuration in conformance with ANSI standard PH 2.33.[1] The contrast of the lines and surroundings should conform to paragraph 4.3.2 of PH 2.33 which cover low contrast targets. The width a line and a space (dimension L of PH 2.33) should be equivalent to the resolution criteria at 400 meters range. A second target should be provided which is identical except that

1. "Method of Determining Resolution," ANSI PH2.33-1969, American National Standards Institute, New York.

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the line-space dimension should be one minute of arc larger than the resolution criteria at 400 meters. The targets should be photographed at 400 meters and the result observed from the projector location. Acceptable resolution should exist when the lines of the targets are detectable after 15 minutes dark adaptation.

The resolution of color film is normally given with respect to a high contrast target (e.g., 1,000 to 1). The color film resolutions published by Eastman kodak show the low contrast resolution in lines per millimeter approximately half that of the high contrast target resolution. Since soldiers in a battlefield environment rarely present a high contrast target, and since lenses can differ in low and high contrast resolution to an even greater degree, the use of the low contrast criteria is highly recommended.

We are hesitant to predict the angular resolution achievable in a practical system due to the many parameters which will affect it. However, as an example, let us choose 35 line pairs per millimeter as the resolution we can put on the screen in a dynamic cine system. The dimensions of the film formats and the number of line pairs we can pack on them at 35 line pairs per millimeter are listed in table 1.

TABLE 1. FILM FORMATS AND RESOLUTION

Film Size	Format	Line Pairs
16mm	9.65 x 7.12mm	337 lines per width of format
35mm	20.95 x 15.24mm	733 lines per width of format

Therefore, the angular width of a resolution element achievable with these formats with a variety of projector angles may be calculated and are listed as table 2.

TABLE 2. ANGULAR RESOLUTION ELEMENTS

	Projector Angle				
Display Width	35°	30°	25°	20°	15°
16mm	6.2'	5.33'	4.44'	3.55'	2.66'
35mm	2.86'	2.45'	2.05'	1.64'	1.23'

Using the angular width of a man of 4.3 minutes, and the assumption that we can identify a spot of light as a man if he is moving and contains 2 resolution elements, we can draw certain conclusions. First, 16mm film is marginally acceptable using only the 15° projection angle. Using 35mm film and a projector angle of 27° or less would be acceptable.

We will use this data in our further discussion of this approach to the simulator configuration design; but it should be emphasized that it is a "best guess" and the real number for projected resolution, which is a major key to the design, must be derived from an actual test.

PERSPECTIVE ANOMALIES

The scene which the trainees and observers view in this particular simulator system should present as nearly as possible the correct perspective that would be observed on the battlefield in order to achieve a reasonable degree of realism. Perspective will affect the ability of the trainee to estimate the range, identity, size, location, and velocity of the target.

Perspective is the technique of representing on a plane or curved surface the spatial relation of three dimensional objects as they might appear to an eye observing the real object from a fixed viewpoint.[2] There are three distinct types of perspective[3] that affect the simulation system under consideration:

True perspective

Distance perspective distortion

Angle perspective distortion

Each of these types of perspective can introduce distortion anomalies into the viewed scene, if they are not properly considered. The first is the only real perspective in the system; the last two are apparent perspectives which may be varied optically.

TRUE PERSPECTIVE. The true perspective of the battlefield scene is a function only of the position from which the scene is viewed, and is not influenced by any other factor. Once this viewpoint is selected as the position for the recording camera, the true perspective is fixed and cannot be altered.

There are two guidelines which may be followed in the selection of the distance of the viewpoint from the scene being recorded in order to insure that the object does not appear unduly distorted. First[4] the lower limit of the viewpoint distance should be approximately three times the length of the

2. Webster's Seventh New Collegiate Dictionary.
3. Focal Encyclopedia of Photography, Vol. 2, Focal Press, New York, 1965, p. 1071-1075.
4. Farmer, J. Harold, et. al., Illustrating for Tomorrow's Production, Macmillan Company, New York, 1960, p. 38.

longest object in the scene. In the present case, let us say this would be a 10 meter tree. Thus, at least a 30 meter viewpoint distance is indicated. Second, the viewpoint distance should be at least as far as the location of the apex of an equilateral triangle whose base is against the front of the scene and equal to the width of the scene.[5] In the present case, the scene being viewed by one camera position is about 50m wide at the near point. Thus, at least a 4.3m viewpoint distance is indicated. Hence, if the scene contains objects of definitely recognizable proportions, (e.g., people or trees) which are nearer the camera position than about 40m, the scene may suffer from objectionable distortion in the true perspective.

In the present simulator, an attempt is being made to record on one camera the true perspective of a scene from five different viewpoints evenly spaced along an 80m line. This cannot be done since the camera can only be physically located at one position. As a compromise, it is recommended to locate the viewpoint (and hence the camera) at the halfway point along the 80m foxhole line in order to minimize as much as possible the distortion in true perspective for all the trainee positions.

DISTANCE PERSPECTIVE DISTORTION. Distance perspective distortion will affect the quality and realism of the projected image of the scene if the distance from which it is viewed does not correspond to the relation,[6]

$$d = mf$$

where,

d = correct distance from screen to viewer

m = magnification of scene on the screen relative to the film

f = camera focal length

In the PMTS, the foxholes will be located at greatly varying distances from the screen; therefore, further analysis is required.

5. Turner, William W., Simplified Perspective, Ronald Press, New York, 1947, p. 43.
6. Asher, Harry, Photographic Principles and Practices, Chilton Book Company, 1968, p. 4-17.

The camera lens used for making the movie will probably have a focal length of 32mm. The magnification of the projection system will probably be,

$$m = \frac{\text{screen width}}{\text{film for mat}} = \frac{15850\text{mm}}{21\text{mm}} = 855\text{X}$$

So, the correct viewing distance in order to have zero distance perspective distortion is found by,

$$d = (755)(32\text{mm}) = 24.2 \text{ meters.}$$

Considering the required PMTS geometry, it is obvious that not all the foxholes could be placed at exactly the same distance. So our next question to answer is how much tolerance can be placed on the 24.2m viewing distance.

The answer to this question cannot be found in the literature, so it was decided to give a best estimate based on experience with reasonably similar situations. We know[7] that the allowable image size difference between the two optical paths in a set of extremely high quality military binoculars is 2 percent. And from experience, we know that portrait pictures taken from closer than about two meters will yield unacceptable facial distortion between the nose, mouth, and ears. The angle subtended by a 5cm nose at 100cm is 0.050 radian, and by a 5cm ear at 115 cmis 0.043 radian, or an angular size error of 0.007 radian, which is a linear size error of 17 percent. Let us then choose a linear image error of 17 percent as a tolerance on our distance perspective distortion based upon the two cases given.

A two meter tall man was chosen as our object under consideration. The length on the screen that a man covers for various ranges was calculated using,

$$l = \frac{(2\text{m})\ P}{R}$$

where,

l = length on screen

p = projection distance

R = range to man

7. Military Standardization Handbook Optical Design, MILHDBK-141, 1962, p. 4-17.

Then the angle subtended by the image of the man at the optimum viewing distance was calculated by,

$$\alpha = \frac{l}{d}$$

where,

l = length on screen

d = correct distance from screen to viewer

Next, using our 17 percent linear image error tolerance, the allowable angular error was calculated for the various ranges using,

$$\Delta\alpha = \frac{0.17\, l}{d}$$

Then the allowable foxhole distances were found by,

$$FX = \frac{l}{\alpha \pm \Delta\alpha}$$

Thus, theoretically the range of distances of the foxholes from the screen in the PMTS should be $20.7m \leq FX \leq 29.2m$. In the final recommended geometry, given Section II in this report, the foxhole distances are shown to be on the order of $21.0m \leq FX \leq 29.9m$ which is satisfactory.

ANGLE PERSPECTIVE DISTORTION. Angle perspective distortion[8] adversely affects a viewed scene when the observation point is not located along the same direction relative to the screen as was the original viewpoint relative to the original scene. In the PMTS device the foxholes and bleacher sections are at varying angles relative to the screen; so consideration must be given to this distortion.

Obviously, all of the trainees should be kept as near as possible to the optical axis of the projector they are interacting with. The required configuration of the line of foxholes prevents this. So as a compromise, the foxhole separation has been reduced such that the greatest distance between two men viewing the same projector is about 17 meters. This presents off-axis angles of about 17°. There are no tolerance guidelines in the literature on angle perspective error, so again we must give an estimate based solely on experience and judgment. We know that we can view the screen in a movie theater from at least 25° off-axis without objectionable distortion. However, under

8. Op. Cit., Focal Encyclopedia of Photography, p. 1073.

those circumstances, the mind is more concerned about the plot of the film rather than the exact angle perspective. Let us say that our best guess at this point is that 17° calculated above will probably be satisfactory.

Also, we should note that size errors introduced by inherent angle perspective distortions actually add in the observer's favor to reduce the distance perspective distortion discussed above. Consider two men approaching the foxhole line, one in the view of the extreme left foxhole and one in view of the extreme right foxhole. The two men in the scene being filmed are at a range of 100 meters from the foxholes, 80 meters apart, and at an angle of 65° from the foxhole base line, and will produce images in the PMTS which are 54mm high on the left of the screen and 40mm high on the right of the screen. The left side man will subtend an angle of 0.018 radian from the viewpoint of the left most trainee, and the right-side man will subtend an angle of 0.019 radian from the viewpoint of the right most trainee, and varying degrees for intermediate men and trainees. In other words, angle perspective distortion, though causing problems of its own, has aided in the reduction of another distortion.

VELOCITY PERSPECTIVE DISTORTION. Assuming that distance and angle perspective distortions are maintained within tolerable limits, we may now proceed to discuss apparent velocity distortions caused by incorrect perspective. Velocity distortions will be introduced into the PMTS system if the rate of change of the perspective of targets is not accurate. Maintaining the perspective of the targets within the limits discussed in Section II above is no assurance that the rate of change of the target perspective will be correct. Of course, the more closely that the tolerance size approaches the correct size of the targets in all frames, then the more closely will be the apparent velocity to the correct velocity of the targets.

The most important consideration that reduces the problem of velocity perspective distortion is the knowledge that each target will not be allowed to remain on the screen for more than five seconds. We expect that the difference between the actual velocity and the apparent velocity of the targets will be undetectable (assuming the tolerances of Section II are adhered to) in the short intervals that the targets will be visible.

RECOMMENDED STUDY ON PERSPECTIVE. It is recommended that a two month experimental task be conducted to more definitely determine some of the above estimated parameters before the final design of the PMTS is fixed. The experiments should consist of movies being made of moving people at the ranges involved; the same movies being displayed on curved and tilted screens at appropriate distances; and a verification of the acceptability of the perspective errors introduced therein.

PROJECTORS AND SCENE BRIGHTNESS

The data on resolution tends to eliminate consideration of the 16mm projectors. However, screen brightness may be an even more compelling factor in this decision.

We estimate that the screen should have a minimum of 6 to 8 foot-lamberts when measured with the projector running without film. The most efficient commercially available 16mm projector produces 2,400 lumens. A 6 foot-lambert display then would limit the screen size to 2,400/6=400 square feet ($37.2m^2$). Using the normal format proportion this would give us a screen of slightly smaller than 5.5 x 7.3m having a 6 foot-lambert brightness. If the camera and projector are intended to cover 30° of the entire gaming area, such a screen would have to be viewed from a distance of 13.7m. We will show that this distance is less than half the required distance when perspective distortion is considered.

Twenty-four hundred lamberts is close to the maximum that can be put through a 16mm frame without burning the film. Even that level will burn film if a frame is stopped in the projector gate for two or more rotations of the shutter. The 35mm frame with 4.5 times more area will permit us to use 4.5 times more light with the same film burning risk. We estimate that the screen area must be approximately 3.5 times larger than the largest 6 foot-lambert screen possible with 16mm film. The 35mm projector should have a brightness of about 8 thousand lumens.

Also, we should note that because of the requirement of producing a video tape of the engagement for critique purposes, it will be necessary to synchronize the projector and the television system. This will necessitate a modification of the projector shutter and pull-down time.

MULTI-SCREEN DISPLAY

Cinerama uses three projectors to present a wide, very high resolution display. It must be taken with three cameras very precisely aligned in a row and framelocked together. The projectors must be framelocked; and when a frame is lost from one of the three films, the identical frame must be removed from the other two films.

The users have agreed that they will permit the use of three or four screens where each screen is separated from the adjacent display by a narrow border. This would have little effect on the cost of a normal cinerama display, but under certain conditions would greatly simplify and reduce the cost of this trainer.

The cameras used to make the movie must be precisely aligned with respect to each other such that the projected image of the areas photographed by each camera visually match the adjacent area in the adjacent film. This requirement is identical to the cinerama requirement and should be accomplished with the same precision.

However, since the cameras will not pan across the scene, we recommend that white tapes be laid on the ground along the lines separating the camera images. Actors could then be forbidden to cross these lines while visible to the cameras. They could either crawl across lines or walk across with the cameras stopped. This will mean that neither the cameras nor the projectors need be framelocked. This feature will reduce the cost per projector and the time and skill required for maintenance.

The cylindrical screens indicated have widths or chords as wide as 14.3m. Using the standard 35mm format, this will produce a screen 8.5m high. However, the targets will appear only in the central and lower 2/3 of the screen; and 1/3 of the image will be sky. It is reasonable to consider reducing the height of the screen 1/3 by simply modifying the gate of the projector. Considering the range of horizontal angles through which the screen will be viewed, it is very doubtful that significant screen gain will be possible.

CONFIGURATION DECISION METHOD

In approaching the problem of the simulator configuration, the above mentioned constraints were considered and the following list of requirements established.

a. The angular width of the gaming area photographed must be the same as the angular width of the scene displayed, to minimize true perspective distortion.

b. The left and right hand fields-of-fire of the trainees in the foxholes should each be contained within the image of one projector to simplify the scoring system.

c. The resolution or angular width of the display should be such that men can be identified at 400 meters and accurately fired upon at 350 meters. Resolution adequate to fire and hit accurately is two resolution elements per man image width.

d. The ratio distance from the screen between the near and far trainee should be 1.4 or less to minimize distance perspective distortion.

e. The angle between the trainee's line of sight and the projector's line of projection should not exceed 17° in order to minimize angle perspective distortion.

f. The building size, as a major cost factor, is directly related to the angular width of the "game" and the radius of the screen.

g. The angular width of the game, and the number and size of projectors used, is directly related to the initial cost and maintenance cost.

TRIAL CONFIGURATIONS. With the exception that certain best estimates (listed above) have been made which should be tested, the following two game-simulator configurations seem to be limits when all factors are considered.

The 90° Game-Simulator Configuration. Figure 2 shows a 90° game plan configuration. The left-hand foxhole has a minimum angle of fire of 22° while the right-hand foxhole has a maximum angle of fire of 41°. The other foxholes have firing angles within this range.

This configuration differs from the real world in that the trainee squad covers the front of one adjacent squad well and then only into a close range of 50 meters, where only a third of the adjacent squads front is covered. The trainee squad's fire covers the front of the second adjacent squad only in the 150-350 meter range. The fields-of-fire of the right-hand foxhole is about 21° off the front.

Figure 3 shows a simulator configuration using this game plan configuration. A 24.25 meter radius screen with its center located on the line of foxholes is used. This provides us with a ratio of 1.44 between the distance from the nearest foxhole to the screen and the farthest foxhole screen distance. The extreme foxholes view the screen with an average 17° angle relative to the projectors as required. Both of these values are close to the acceptable perspective tolerances estimated. The chord of the combined screens is 36 meters.

The only serious problem with the display, if one accepts the narrow 90° game plan, is the 15° to 31° fields-of-fire of the right-hand foxhole. This is, of course, apparent only to the man in the foxhole and we believe the effect can be reduced significantly by giving the end of the foxhole a 10° increased angle.

The 100° Game-Simulator Configuration. This configuration involves two 25° trainee game areas separated by 50° (see figure 4). It uses two normal 25° projector images for the trainee game area plus a 2:1 anamorphic display for the 50° center section.

The fields-of-fire in the gaming area are within a minimum of 32° and a maximum of 45°. This covers the front of the adjacent and 2nd adjacent squads somewhat more realistically than the 90° game plan configuration.

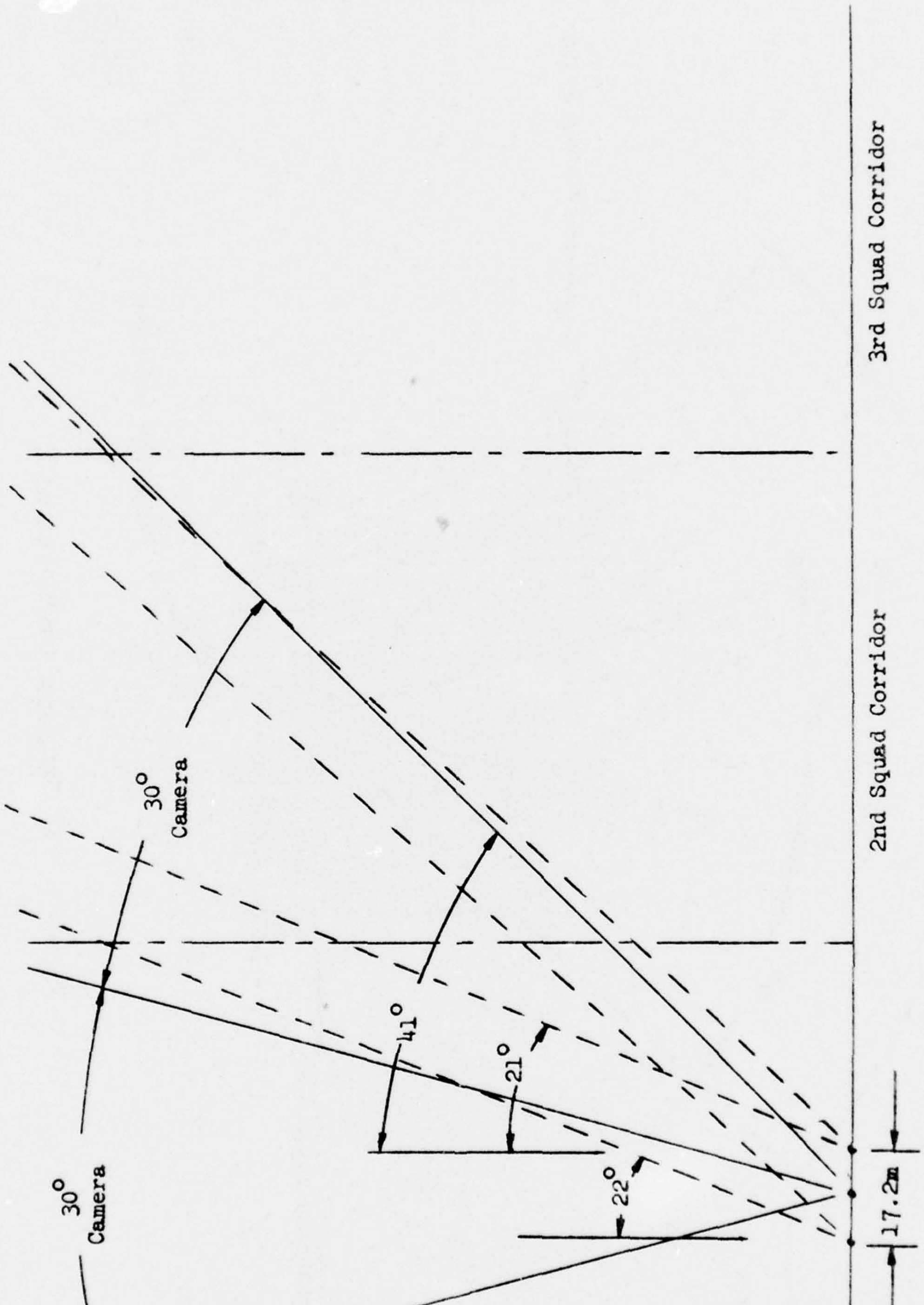

Figure 2. 90° Game Plan Configuration

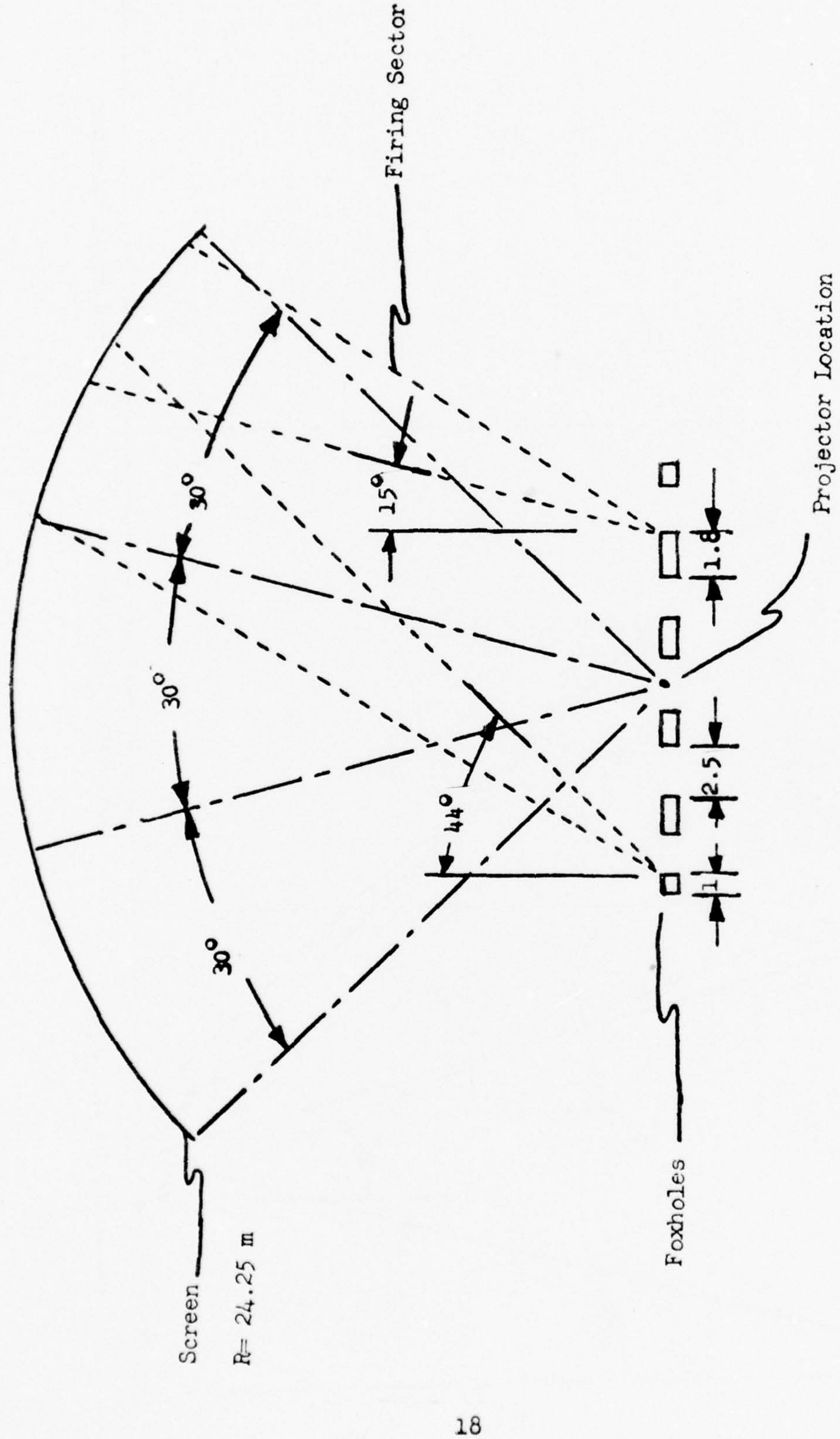

Figure 3. 90° Simulator Configuration

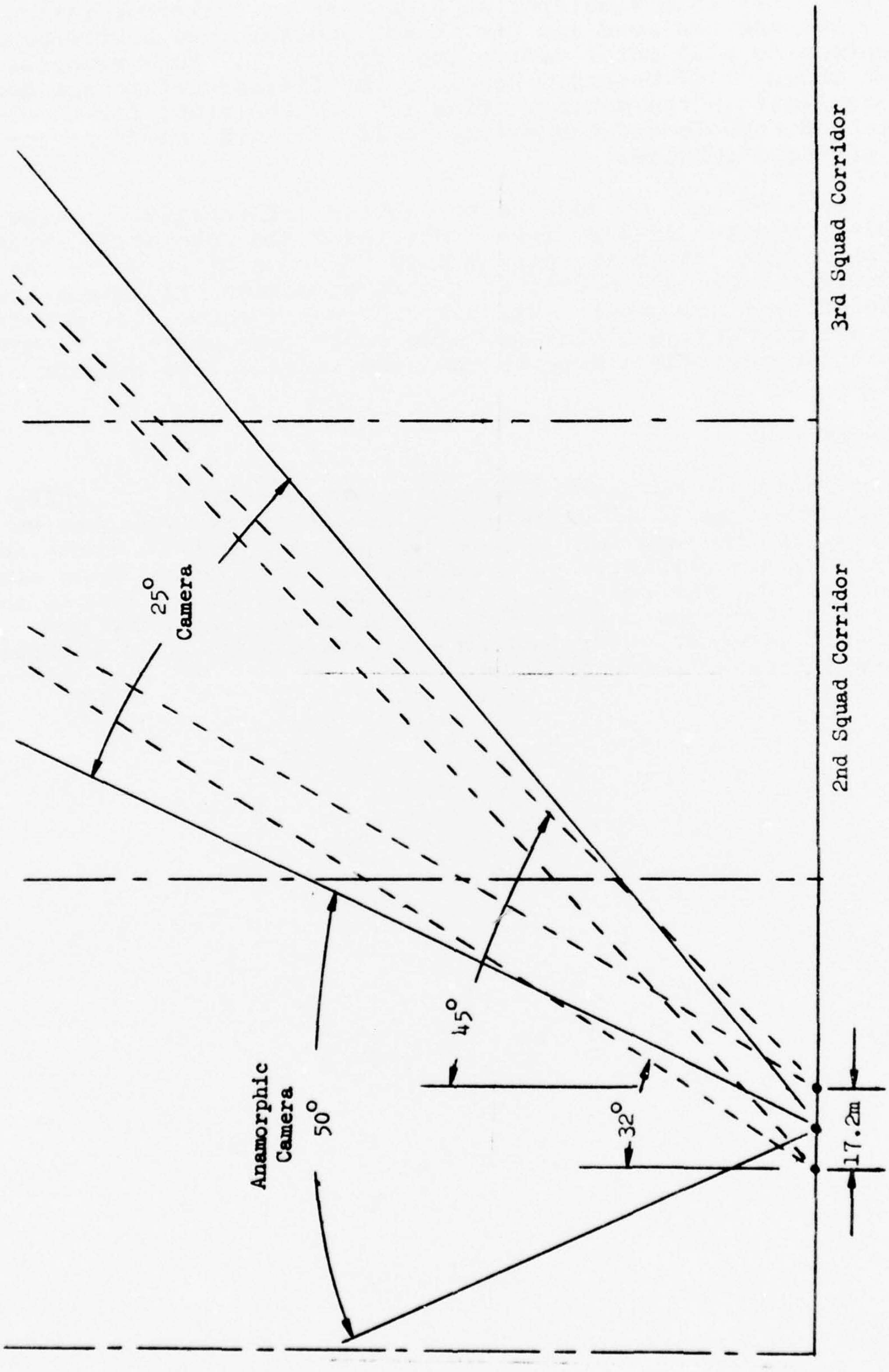

Figure 4. 100° Game Plan Configuration

Translated to a simulator we find that to achieve a ratio of 1.4 between the near and far screen distance, we must expand the screen to a 30 meter radius (see figure 5). This produces a screen chord of 47 meters. However, the fields-of-fire are much more realistic - the minimum being 17° off the front for the right-hand foxhole and the maximum being 49° off the front for the left-hand foxhole.

A decision must be made as to whether the relatively large building required is justified. The increased resolution in the fields-of-fire, which is considerably improved by reducing the field width from 30° to 25°, and improved screen brightness are the benefits. The central 2:1 anamorphic projector will require twice the brightness of the two side projectors at the film gate; but with the decreased area of the side screens this appears feasible.

DESIGN TESTING

The principle purpose of the above two exercises in configuration design is to illustrate the idea that the estimates we have made in the required projected resolution and the acceptable perspective distortion, have a great effect on the building size and, therefore, the cost of the simulator. We feel strongly that the testing programs recommended in projected resolution and acceptable perspective distortion will pay dividends in lowering the overall risk factor and cost.

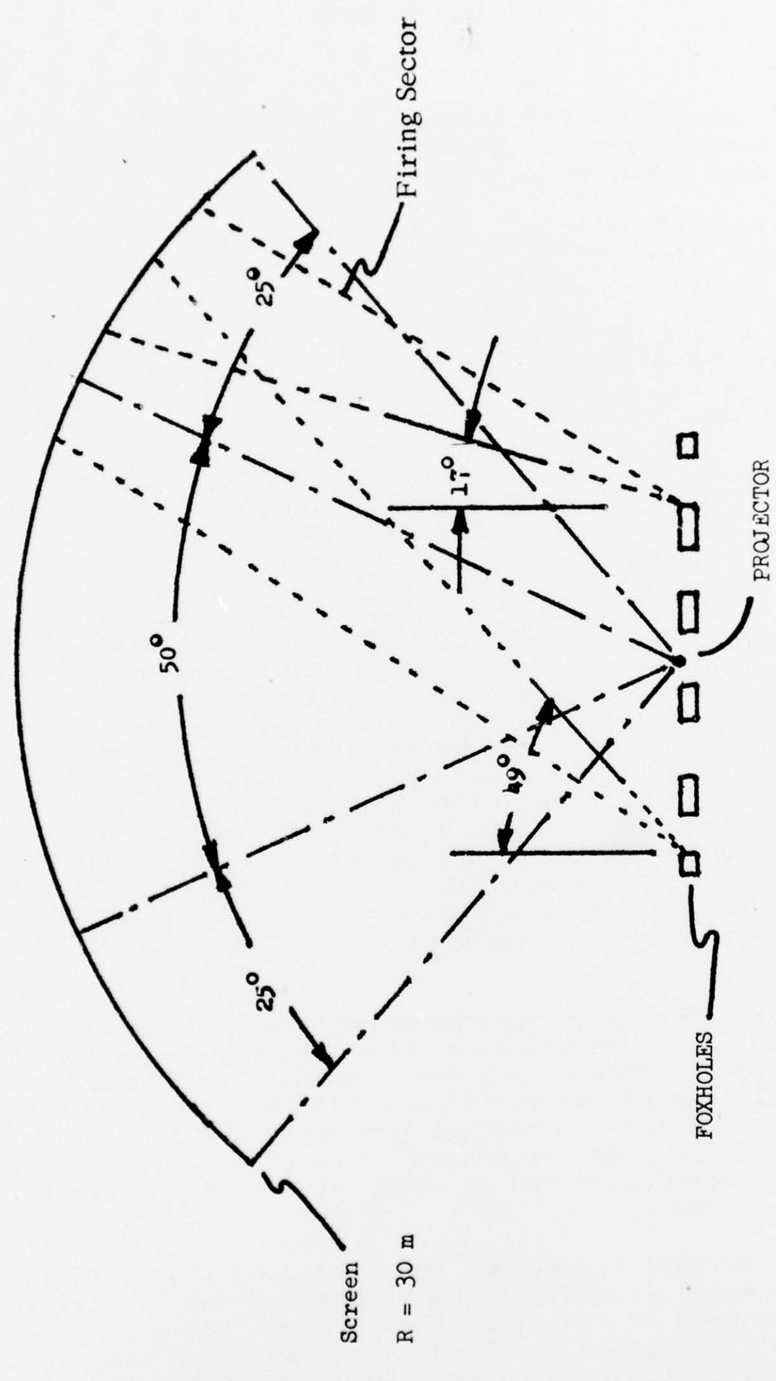

Figure 5. 100° Simulator Configuration

SECTION III

SIMULATION OF FIRE

REQUIREMENTS

The PMTS presents a battlefield scene with enemy attacking over a 4 or 5 squad front. Visible simulation of fire on the screen will come from two sources:

a. When a trainee in one of the six foxholes fires his weapon, he will flash a visible light source on the screen which will appear at his aim point.

b. To simulate other squad fire covering the front of the trainee squad and adding to the fire of the trainee squad, there will be preprogrammed flashes of light impinging near and hitting visible targets.

The net result of the visible simulation of fire will be to demonstrate to the observers in the bleachers how fire is distributed and the mutual protection feature of the Integrated Parapet Foxhole Concept.

The fire distribution that must be simulated can be calculated as follows. In the mission to be simulated, each infantryman has 120 rounds to fire in approximately 10 minutes. The trainee squad in the foxholes has a total of 1,200 rounds. If one examines the geometry of overlapping fire, there are no more than 10 weapons covering a squad front from adjacent squads for any given range. If the enemy attacking front has a depth less than 100 meters, no more than ten weapons will be firing at it at one time. This means that for each squad front there will be 1,200 rounds fired during the 10 minute period or 1,200 rounds in 600 seconds which gives a uniform rate of 2 rounds/sec/squad front. For the total screen, which simulates five squad fronts, there will be approximately ten rounds per second flashing on the total screen.

A feasible and easily implemented approach to simulating the preprogrammed flashes of light is to go through the motion picture film, frame by frame, and make pin-prick punctures where one desires the flashes to occur. This would require 2,400 pin-pricks in the film for the central projector and 1,200 pin-pricks for each of the two side projectors. The pin-pricks would sometimes be made near misses and at times hits on the visible targets or their cover.

There are several approaches for providing visible flashes on the screen which originate from attachments to the rifles that are being used in the simulator. Two of the more promising approaches utilize either a pulsed, arc-type flash lamp or a continuous-wave helium neon laser. An analysis was performed

for both of these approaches comparing size, complexity, and cost. Other approaches, using standard lamps and pulsed lasers were considered too complex, costly, or large. One approach is analyzed which provides the visible flashes on the screen from a source not attached to the rifle.

The assumed requirements for the light flashes on the screen are:

a. The visible light spot should not cover more than one milliradian (3.4 arc minutes) when viewed from the observer's position. This tolerance results from the accuity of the observers, the accuracy of the M-16 rifle, and the required scoring accuracy.

b. The flash duration should be on the order of 1/100 seconds to avoid the improper scores of due to trainee jerk after firing.

c. The maximum flash rate required is 2 per second since the trainee is not allowed to fire in the automatic mode.

d. The rifle mounted device should be as small and light weight as possible.

WEAPON MOUNTED FLASH LAMP APPROACH

The first approach considered utilized a compact arc, pulsed xenon flash lamp which is manufactured by United States Scientific Instruments, Inc. The smallest lamp they produce is the 1 CP-m which is 8.26cm long by 2cm in diameter. The arc size is approximately one millimeter which when imaged by a 1 meter focal length lens would give a one milliradian spot size. The pulse duration is on the order of 10 microseconds. The two flashes per second capability can be easily achieved by using multiple capacitor circuits. The average power required per flash is 20 watts and will produce a screen luminance of approximately 8 ft-lamberts. The greatest drawback of this approach is the size (e.g., the 1 meter focal length lens) plus the fact that it is still necessary to mount a gallium arsenide infrared laser for scoring purposes.

WEAPON MOUNTED LASER APPROACH

The second approach fulfills two requirements at once. It serves as the scoring signal and produces a visible light spot on the screen that can be differentiated from the preprogrammed pin-prick light spots. This approach uses a one milliwatt helium-neon laser, the size of which is: length, 21cm, diameter 4.5cm, and weight 430gm. When equipped with a 1/100 second shutter, the apparent luminance of the flash would be 3.4 foot-lamberts in a one milliradian spot on the screen.

If we use small lens about 5cm long and 1cm in diameter, the spot size on the screen can be reduced in area by a factor of 10 giving 34 ft-lamberts luminance; and since this is just the resolution limit of the eye, no further apparent increase in luminance through spot size reduction is possible.

Scoring can be aided by placing a narrow band spectral filter in front of the recording television camera. The filter would lower all signals relative to the laser and give excellent signal to noise characteristics. Scoring will be discussed in more detail in the following section.

According to the new laser safety standard,[9] a pulse of visible laser light is eyesafe if the total energy in that pulse does not exceed 0.25×10^{-3} Joule. Hence, a one milliwatt helium neon laser is eyesafe if its pulse duration does not exceed 0.25 seconds. In the proposed system, the pulse duration is 0.01 second. Hence, a 25 times safety factor is provided in this system approach.

REMOTE LIGHT SOURCE APPROACH

A third approach for simulating weapon fire by visible light spots is to use one or more light sources (either laser or pulsed flash lamp) remote from the weapons. A gallium arsenide, infrared laser would have to be mounted on and boresighted with each M16. When the weapon was fired, a sonic or electric signal from the trigger would indicate which weapon fired. The television system would locate the position of the infrared spot on the screen and a signal would be sent to the light beam positioning system which would project a visible light spot either on the target hit or at the proper lead angle. The positioning system could be one or a combination of several approaches utilizing electrooptical deflectors, acoustooptical deflectors or gimballed mirrors. This approach would eliminate the need for individual 1-2 lb. lasers mounted on the weapons and the need for a umbilical cord, however, the umbilical cord would still be required for simulation of rifle recoil as discussed in the next section.

SIMULATED RIFLE RECOIL

A compact, electronic controlled, experimental weapon recoil mechanism has been developed by the Physical Science Laboratory, NAVTRAEQUIPCEN, for demonstrating with an electro-optic weapon trainer, for the Universal Infantry Weapon Simulator. The recoil mechanism is installed within the trainer rifle weapon with a connecting power cord, power supply, and electronic pulsing

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9. "Standard for the Safe Use of Lasers," ANSI Z136.1-1973, American National Standards Institute, New York, April 16, 1973.

circuit located external to the rifle. Preliminary tests are promising although impact forces are limited to about five pounds, or about one-half the recoil of a M-16 rifle, but somewhat more than an M-16 with a muzzle brake. Development effort remains for increasing impact forces and demonstrating automatic firing feasibility. Some degree of recoil simulation is considered important because it interferes with aiming and aiming realism.

SECTION IV

TECHNIQUES FOR SCORING

SUBSYSTEMS

The scoring of weapon fire depends on several different subsystems which consist of:

a. Target data storage.

b. Aim and fire indication system.

c. Aim and fire detection system.

d. Logic circuitry for hit indication.

TARGET DATA STORAGE

In order to obtain the frame-by-frame target location and size, the developed motion picture film must be carefully measured frame-by-frame and the data recorded. The process can be automated to some extent by using a light table, an x-y pickup device and a recording tape but even this procedure is basically a manual type job. One such device is the L-W Model 110 photo digitizer, which can transfer x-y coordinates onto magnetic striping. The target size must be measured so that the "hit" tolerance can be determined. In cases where there is a target velocity across the direction of view, the target location must be calculated based on the time of flight of an M-16 round from the trainee to the target; the target location would include the proper lead required to obtain a hit.

There are a number of methods for storing the data including the utilization of the sound tracks on the motion picture film. The parameters that must be considered in determining feasibility are the number of targets, the precision required for target location, the tolerance on a "hit," the number of sound tracks, and the film speed variation. An analysis of this approach was performed by John McKechnie.[10] With typical values of 0.6 percent film speed variation, a 17 bit word for target location, 3 sound tracks (one is reserved for sound), and a four bit word for x, y tolerance, only 24 targets could be so located. Since we are considering a mission where the enemy attacks with a 6:1 personnel force, and five trainees are helping to cover two squad fronts to their flank, there may be more than 24 targets visible in some frames. An alternate approach to overcome target number limitations would be to have the film sound track cue a computer sequential memory storage; but this approach would require further analysis.

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10. McKechnie, John C., "Recording of Multiple Target Locations on 35mm Movie Film Adjacent Soundtracks," unpublished, 8 Jan 76.

AIM AND FIRE INDICATION SYSTEM

The approach to aim and fire detection proposed in reference b uses a weapon mounted semiconductor, infrared laser to generate a spot on the screen, and a closed circuit television camera to view the screen and measure spot location. Since the television has no method of discriminating between infrared spots, each weapon is inhibited sequentially so that the weapons are separated on a time basis. This means that there is a possibility that when a man squeezes the trigger, there could be a 5/30 second (10/30 second in the proposed system of reference (b)) time delay before the laser fires. There are two objections to this approach. The first is that the trainee may move as quickly as 1/100 seconds after he squeezes the trigger so that when the laser fires a 5/30 seconds later it does not indicate where he was aiming when he fired. The second is that, since a visible light spot is desired to show distribution of fire, it would be more economical to use that light spot to indicate weapon aim and firing (actually, a visible light spot requirement originating on the weapon necessitates an umbilical cord so that a trigger pull could generate a signal indicating that weapon A fired and the light spot indicates where weapon A fired, etc.)

The probability of two rounds being fired in the same 1/30 second interval is very low. The parameters involved are that five men are firing 600 rounds in a 600 second period and that the 600 second period can be divided into 600 x 30 or 18,000 intervals 1/30 seconds long. Since there are a large number of possible targets, and they are uniformly appearing and disappearing; there will always be some visible target on the screen. Based on the constant availability of targets, the probability of a trainee firing in any one of the 1/30 second intervals is uniform. Thus, the probability of a trainee firing one of his 120 rounds in one of the 18,000 time intervals is 120/18000. The probability of two trainees firing in the same interval is (120/18000) . (120/1800); but since there are five ways to select two trainees from five trainees, then the probability of two trainees firing in the same interval is

$$p = 5\,(120/18000)^2 = 0.00022.$$

The probability calculated is very low; however, it does not take account of three important factors. One is the fact that the trainee can probably single fire as fast as two rounds per second which could significantly alter the assumed uniform distribution. The second factor is that he will tend to fire more at closer targets which will occur near the middle of the motion picture film. And the third factor, which may cause cluster firing, is his tendency to fire when he hears his neighbor firing. Since the magnitude and reliability of the factors

affecting the uniformity of fire cannot be predicted apriori, we recommend that statistical data for rates of fire be collected on the prototype to establish a confidence level in the scoring. We feel that the confidence level will exceed 99 percent and be completely acceptable from a training point of view.

If it is decided that complete discrimination of fire is required, two approaches should be investigated. One would be to develop inhibiting circuitry so that in that small percentage of cases when two or more trainees attempt to fire during the same TV frame, the trigger pulled first fires the first weapon and inhibits other weapons from firing for 1/30 second. The trigger pulled second sends an electrical signal to a memory storage device which stores the "fire signal," inhibits the remaining weapons for 2/30 second, and then fires the second weapon 1/30 second later. The third trigger pulled sends a signal to the memory storage device which stores its "fire signal," inhibits the remaining weapons for 3/30 second, and then fires the third weapon 2/30 second later. Similarly, inhibiting circuitry is built for weapons four and five. Note that any of the five trainees could send in the first trigger pull signal during any particular TV frame which lasts 1/30 second. In other words, this approach greatly reduces the probability that any trainee will receive a delay in the weapon firing. The probability that a weapon will be delayed 1/30 second is the same as the probability that two trainers will fire in the same 1/30 second. The probabilities that the various delay times would be imposed by the above described inhibiting circuitry were calculated assuming uniform distribution of fire and are listed in Table 3.

TABLE 3. PROBABILITY OF DELAY IN WEAPON FIRING USING INHIBITING CIRCUITRY

Delay Time	Probability of Occurrence
0 second	99.96%
1/30 second	0.04%
2/30 second	0.0003%
3/30 second	0.000001%
4/30 second	0.0000002%

The probability of any delay is very low. And the 1/30 second delay would probably be tolerable in terms of weapon movement as affected by jerk. Hence, the inhibit type circuitry should provide an excellent scoring system.

The second approach would be to monitor the output power of the five lasers and impose 10% intensity level differences so that screen luminance would vary from 34 ft-lamberts to 15 ft-lamberts and the lasers could be discriminated in the television circuitry by light level.

AIM AND FIRE DETECTION SYSTEM

With the basic laser and some simple optics mounted on the weapon, it is possible to obtain a one-minute-of-arc laser beam divergence. The distance from the foxhole position to the screen may typically vary from 23 meters to 33 meters so that the laser spot diameter on the screen may vary from 6.7mm to 9.6mm. If a 1,000 line television system is positioned 28 meters from the screen and scans a 30° field of view, then the television system could only resolve a 23mm laser spot diameter (considering 900 active TV lines and .7 kell factor). This means that the laser spot diameter does not limit scoring precision. It also means that the maximum aiming precision required of the near trainee is 3.4 minutes of arc and for the far trainee 2.4 minutes of arc.

Consider a target (i.e., man) 2 meters tall and 1 meter wide. At 350 meter range, he will have a size on the motion picture screen of 160 x 80mm and at 75 meter range his size will be 747 x 373mm. These sizes are all larger than the television or laser resolution elements so there should be no inaccuracy in scoring hits or misses. However, in order to balance the difficulty of hitting targets from any foxhole position, the tolerance on the x-y location of a target should be modified depending on which weapon fired. This tolerance should take into consideration the balancing mentioned in Section II.

Another problem that arises in precision of firing is storing the proper lead angle for moving targets. In calculating the lead required for a hit, we must consider the distance the target will move in the time it takes for the bullet to travel from the weapon to the target. The equation that must be solved is:

$$l = \frac{V_t \cdot r}{V_b}$$

l = lead distance in meters

r = target range in meters

v_t = component of target velocity normal to the line of sight

v_b = bullet velocity

Consider the following set of parameters:

$$r = 350\text{m}$$

$$v_t = 4 \text{ m/sec}$$

$$v_b = 1{,}000 \text{ m/sec}$$

then l = 1.4 meters which means that if the trainee is to be awarded a hit, he must lead the target by 1.4 meters or about two body widths. The following table indicates what happens to the above parameters as a function of range.

TABLE 4. LEAD DISTANCE PARAMETERS

Range	Time of Flight	Lead
350 meters	0.35 sec	1.4 meters
300 "	0.30 "	1.2 "
250 "	0.25 "	1.0 "
200 "	0.20 "	0.8 "
150 "	0.15 "	0.6 "
100 "	0.10 "	0.4 "
75 "	0.075 "	0.3 "

In order to be realistic, the lead should not be a constant value. The target will probably jump from behind cover, run for 4 to 5 seconds, and then dive for cover again. If the trainee spotted the target going behind cover and is waiting for him to jump, then the lead will be practically zero; but if the trainee tracks him for a few seconds, then he must have the full lead.

Consideration should be given to the lead problem. Since the visible laser is boresighted with the weapon aim point, his visible fire indication on the screen will be in front of the target when he has the proper lead. The trainee must be instructed that for crossing targets he will only get a hit indication on his visible hit indicator, if he has fired with the proper lead, and his visible spot on the screen will indicate to him the amount of lead he was using. Trainee observers should be likewise instructed. Both groups will receive some indication of a hit other than the visible spot on the screen, such as a visible light at the trainee station.

By using visible lasers of at least 1 milliwatt power, the detector sensitivity problem is virtually eliminated. The recording closed circuit television camera will be adjusted for the light level of the battlefield scene, i.e., approximately 5 to 10 foot-lamberts. Each of the ten weapon lasers will have a brightness of 17 to 34 foot-lamberts over its usable lifetime of approximately 1,000 hours. Hence, the laser spots will easily be sensed by the television camera.

LOGIC CIRCUITRY FOR HIT INDICATION

The logic circuitry will essentially be designed to fulfill the requirements of the approach proposed in reference (b); however, there will be a number of simplifications. First, there will only be five weapon signals to process for each of two CCTV systems. Second, a controller/sequencer will most likely not be necessary, because of the low probability of simultaneous firings within one television frame (1/30 second). If a controller sequencer is necessary, it will be an inhibit type device not a cyclic, time-sharing device. Third, if an umbilical cord is used on the weapon, radio transmitters and receivers would not be necessary.

SECTION V

SOUND REQUIREMENTS

Battlefield noises will add a great deal of realism to the particular simulator under consideration. It is recommended that the movie screen be equipped with a high quality stereo sound system to convey the sounds of enemy fire, mortar blasts, etc. Each trainee position in each simulated foxhole should be equipped with a speaker and weapon noise tape, such that, when the trainee fires his simulated weapon, he will hear a loud bang similar to the actual weapon noise. Omission of the suggested high-quality audio equipment will reduce the possibility of inducing near battlefield stress conditions upon the trainees.

SECTION VI

CONCLUSIONS

Let us summarize in a general manner the results of our research study:

a. Due to a change in the training objectives and mission requirements, previously proposed systems are not totally satisfactory.

b. Several alternative simulator configurations have been suggested and analyzed.

c. Several methods for simulation of weapon fire have been proposed and analyzed.

d. A method of weapon scoring has been proposed.

e. Audio requirements have been mentioned.

f. Three areas of study and experimentation should be addressed in the early developmental states:

(1) Perspective distortion

(2) Rates of weapon fire

(3) Visual scene resolution

Several relatively arbitrary decisions must be made in certain areas before a final design can be set:

a. What size building will be provided?

b. Is an umbilical cord allowed on the weapon?

c. Is recoil required on the weapon?

d. Will the visible hit indicator be on or off the weapon?

In conclusion, we feel that the Panoramic Motion Target Screen to simulate and instill confidence in the Integrated Parapet Foxhole concept of rifle squad defense appears feasible. There are no areas of technology for the system that will require a great amount of research. Some developmental work and experimentation will be needed to insure that the final configuration does satisfy the training objectives prescribed and discussed herein; but we foresee no major difficulties.

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